Chapter 1

Requirements for Sustainable Housing Design

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Abstract

Buildings including homes are related to a variety of environmental, social, and economic problems. In the twenty-first century, especially two major problems, namely "climate change" and financial problems resulting from "aging population," are expected to become more serious globally. In order to curb the progress of climate change, building sector has to strengthen "mitigation" measures, including improvement in energy efficiency of buildings and utilization of renewable energy. Building sector must also strengthen "adaptation" measures, aiming to reduce adverse effects caused by climate change. On the other hand, homes need to be transformed into those which contribute to reduce illnesses and injuries, which tend to increase in accordance with aging population. Taking accessible and universal design into homes is effective to increase mobility of occupants as well as to prevent injuries. Homes are used for a very long time; therefore, these considerations need to be comprehensively taken into homes from the beginning.

Keywords: climate change, mitigation, adaptation, aging population, accessibility, universal design

1. Introduction

Buildings including homes are the places where people spend the largest part of their time. According to a survey in the U.S., people spend 87% of their time in enclosed buildings, made up of 69% in residences and 18% in other types of buildings [1]. Meanwhile, buildings including homes are used for a very long time. Longer lifespan of buildings is desirable, since it leads to reducing natural resources for construction as well as waste.

Sheltering occupants from severe climate and weather, homes are expected to protect occupants' health, safety, and well-being. In the twenty-first century, two major significant changes progress inside and outside houses. They are "climate change" and demographic change, namely "aging population". That is to say, it is regarded as certain that human activities influence climate and increase extreme weather events, while humans themselves increase in average age.

Facing these changes, homes also have to be changed toward sustainability. Focusing mainly on climate change and aging population, this chapter describes main points that the two major changes require homes to deal with, so as to lead to sustainability.

2. Climate change and buildings

2.1. Climate change: observed changes and their causes

Greenhouse gas (GHG) emissions originating in human activities have grown, and recent global GHG emissions are the highest in the history. According to the Intergovernmental Panel on Climate Change (IPCC), GHG emissions from the building sector have more than doubled since 1970 to reach 9.18 $GtCO_2$-equivalent in 2010, representing 19% of all global 2010 GHG emissions. In 2010, the building sector accounted for 32% (24% for residential and 8% for commercial) of total global final energy use and 51% of global electricity consumption [2].

Human influence on the climate system is clear. Atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have obviously increased. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (very high confidence) [3].

It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia, and Australia [3]. Extreme heat events currently result in increases in mortality and morbidity in North America (very high confidence) and in Europe with impacts that vary according to people's age, location, and socio-economic factors (high confidence) [3]. Also, in recent Japan, there has been an increasing trend in the number of deaths from heat stroke (**Figure 1**); experts point out that a cause of this increasing trend is recent rising tendency in temperature [4, 5].

It is likely that extreme sea levels have increased since 1970, being mainly the result of mean sea level rise. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased [3]. It is virtually certain that intense tropical cyclone activity has increased in the North Atlantic, since 1970 [3]. Similarly, according to a latest study, typhoons that strike East and Southeast Asia have intensified by 12–15% since the late 1970s [6].

2.2. Warming versus cumulative CO_2 emissions

The Fifth Assessment Report of the IPCC has concluded that "cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond" [3].

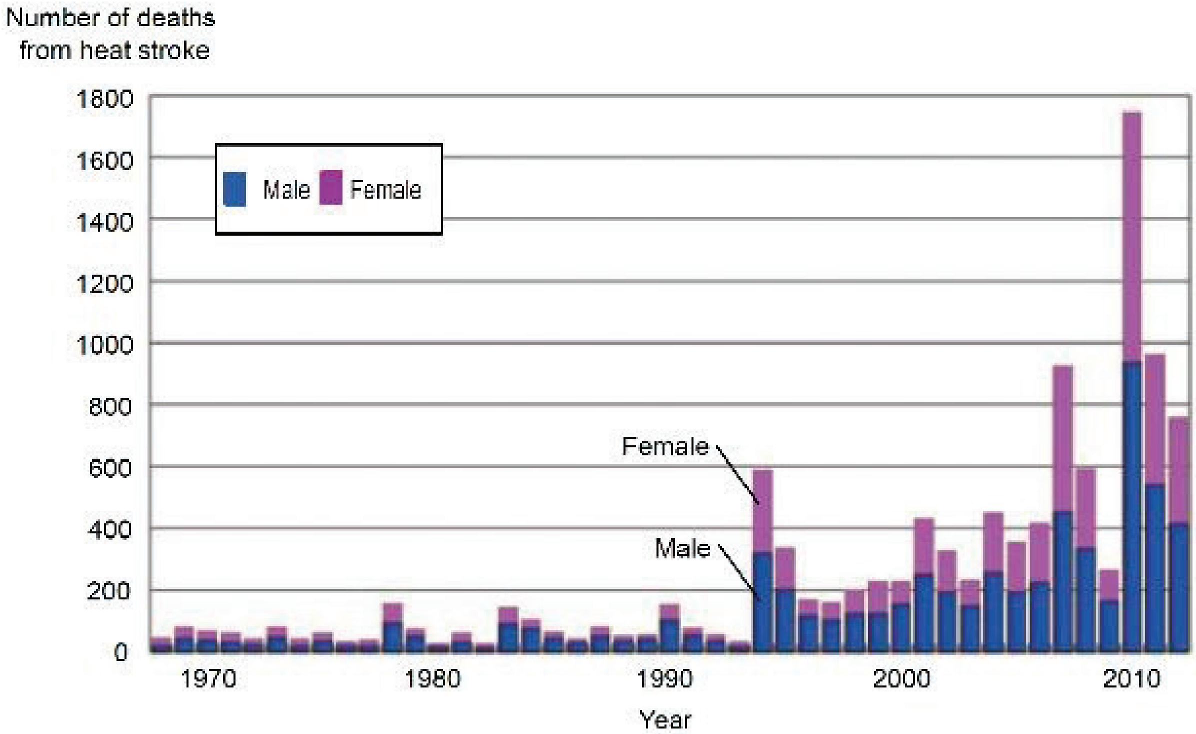

Figure 1. Changes in the number of annual deaths from heat stroke by sex in Japan (1968–2012) [4]. Source: Ministry of Health, Labour and Welfare, Vital Statistics.

"Cumulative emissions of CO_2" means the total amount of carbon dioxide that human beings have emitted into the atmosphere [7].

Figure 2 demonstrates the relationship between "cumulative anthropogenic CO_2 emissions from 1870" and "temperature change relative to 1861–1880". The colored plume illustrates the multimodel spread over the IPCC's latest four scenarios named representative concentration pathways. Meanwhile, the hollow ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100. The "baselines" means scenarios without additional efforts to reduce GHG emissions beyond those in place today. The ellipses with figures show the scenario categories of the IPCC's Working Group III, according to levels of efforts to reduce GHG emissions; figures such as "530–580" mean projected CO_2-equivalent concentration levels (in ppm) in 2100. The black-filled ellipse represents observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. In short, both the plume and ellipses in **Figure 2** indicate a strong, consistent, and almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 [3].

Figure 2 also shows that "regardless of the scale of reducing GHG emissions, cumulative CO_2 emissions will increase, and therefore, global surface temperature is projected to rise over the 21st century" [3, 8]. As a result, the adverse impacts of projected climate change, such as heat waves, floods, cyclones, and wildfires, will increasingly become more severe.

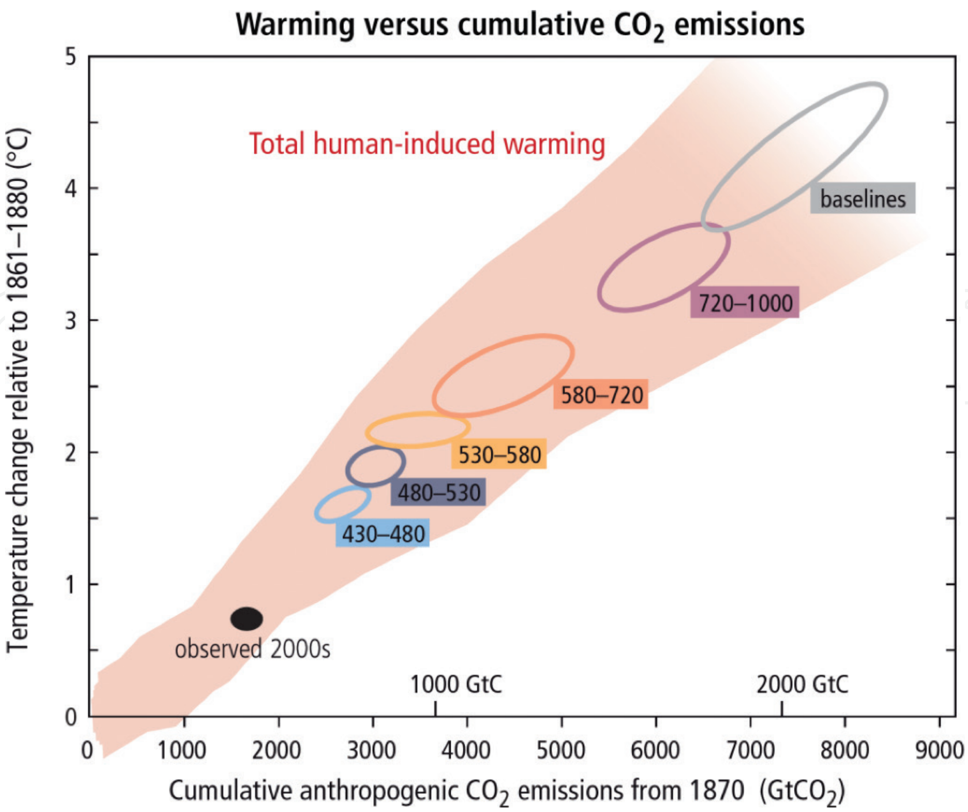

Figure 2. Relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 [3]. Notes: (1) Colored plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four representative concentration pathways over all times out to 2100 and fades with the decreasing number of available models. (2) The hollow ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in Working Group III. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. (3) The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties.

2.3. Mitigation, adaptation, and sustainable development

Reducing climate change risks requires "adaptation" as well as "mitigation" (**Table 1**) [3, 8]. The IPCC defines "mitigation" as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases" [3]. Mitigation measures include energy conservation, harnessing renewable energy, and absorbing CO_2 through afforestation. On the other hand, "adaptation" is defined as "the process of adjustment to actual or expected climate and its effects" [3]. Adaptation seeks to moderate or avoid harmful influences caused by climate change [3]. Adaptation strategies include heatstroke prevention, measures against floods, cyclones, drought, infectious diseases, and high-temperature damage to cultivated crops.

Neither adaptation nor mitigation alone can avoid all climate change impacts [7]. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change [3].

The chapter of "Climate-Resilient Pathways: Adaptation, Mitigation, and Sustainable Development" in *Climate Change 2014* explains, "It takes sustainable development as the ultimate goal and

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Strategy	Definition	Typical examples
Mitigation	Human intervention to reduce the sources or enhance the sinks of greenhouse gases	• Energy conservation • Harnessing renewable energy • Conserving timber resources • Carbon dioxide capture and storage
Adaptation	Process of adjustment to actual or expected climate and its effects	• Measures against inland and coastal floods • Measures for dealing with water shortages • Heatstroke warning systems • Building resilient infrastructure

Table 1. Definition and typical examples of mitigation and adaptation.

considers mitigation as a way to keep climate change moderate rather than extreme. Adaptation is considered a response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios of climate change" [9].

2.4. Mitigation and adaptation strategies in building sector

There are a variety of mitigation and adaptation options in the building sector as well as other sectors.

Buildings represent a critical piece of a low-carbon future and a global challenge for integration with sustainable development (robust evidence and high agreement) [2]. Existing and future buildings will determine a large proportion of global energy demand. Current trends indicate the potential for massive increases in energy demand and associated emissions. However, if today's cost-effective best practices and technology are broadly diffused, final energy may stay constant or even decline by mid-century, as compared to today's levels [2].

The IPCC's Fifth Assessment Report has classified building sector's mitigation options by strategies: improvement of "carbon efficiency", "energy efficiency of technology", and "system efficiency", as well as "service demand reduction". **Table 2** shows extracts from such mitigation options of these four strategies [2].

In addition to mitigation strategies, adapting building designs for climate change is about dealing with the unavoidable [10]. There is no consensus on definitions of climate adaptive buildings [2]. However, there is growing awareness that design practices need to take into account the predictions of increased risk and intensity of extreme events [10].

Table 3 presents main predicted risks and examples of adapting building/housing design options [10, 11]. Strategies to reduce climate-related risks differ across regions [3]. Therefore, people involved in promoting sustainable design and designing sustainable buildings in each region need to appropriately predict future risks and plan effective strategies.

Mitigation strategy	Major mitigation options of buildings
Carbon efficiency	• Building integrated renewable energy system • Fuel switching to low-carbon fuels
Energy efficiency of technology	• High-performance building envelope • Efficient appliances and lighting • Efficient heating, ventilation, and air-conditioning systems
System efficiency	• Passive house standard • Net zero energy and energy plus buildings
Service demand reduction	• Behavioral change • Lifestyle change

Table 2. Major mitigation options of buildings by strategies.

Extreme weather events and impacts	Examples of adaptive strategies for building/housing design
Increasing temperatures	• High thermal insulation • External shading • Natural ventilation • Green roof
Cyclones and storms	• More wind-resistant buildings • Select impact-resistant exterior materials • Install window protection
High intense rainfall, flooding, and rising sea levels	• Use water-resistant materials • Raise buildings off the ground
Low rainfall and drought	• Use water-saving fixtures and appliances • Harvest rainwater
Wildfire	• Use fire-resistant exterior materials

Table 3. Examples of adaptive strategies for building/housing design by impacts.

3. Aging population and housing

3.1. Aging population: fierce threat to public finances

While growing human activities are aggravating climate change and seriously harming environmental sustainability, "aging population" is becoming a fierce challenge to social and economic sustainability. According to the book titled *Agequake*, in the twenty-first century, there will be more people older than younger ones. The "agequake" will turn the age pyramids upside down, first in Japan and Europe, but ultimately throughout the world [12]. Europe is projected to remain the most aged region in the coming decades, with 34% of the population aged 60 years or over in 2050 [13]. The European Union warns that the aging of the population is becoming a growing challenge to the sustainability of public finances. The increase of the ratio between the number of retirees and the number of workers will amplify expenditure on public pensions and health and long-term care and thus put a burden on maintaining a sound balance between future public expenditure and tax revenues [14]. The demographic change of Japan is more drastic (**Figure 3**); Japan's population aged 65 years or over is projected to reach about 40% in 2060 [15]. Similarly, demographic pressures will continue to mount and add to concerns about fiscal sustainability in Japan [16].

3.2. Links between unsuitable housing and ill health

Ed Harding: International Longevity Centre UK clearly states, "Suitable housing is central to the challenge of population ageing" [17]. In the UK, older people spend between 70 and 90% of their time in their homes, much more than any other age group [17]. A survey in Japan also indicates similar results; people aged 70 years or over spend on average about 83% of their time in their houses, which is considerably larger than any other age group [18]. Unsuitable housing has direct and proven linkages with ill health, including allergy, asthma, heart disease, hypertension, falls, and annoyance [17, 19, 20].

For example, in Japan, illnesses and deaths of elderly people are related to lower thermal performance of homes in both winter and summer. In winter, many people die by drowning in homes' bath. The number of sudden bath-related deaths increased to 4866 in 2014 [21], which exceeded the number of traffic deaths in the same year, namely 4113 [22]. Approximately 90% of the bath-related deaths are the elderly, people aged 65 years or over [21]. Monthly data on

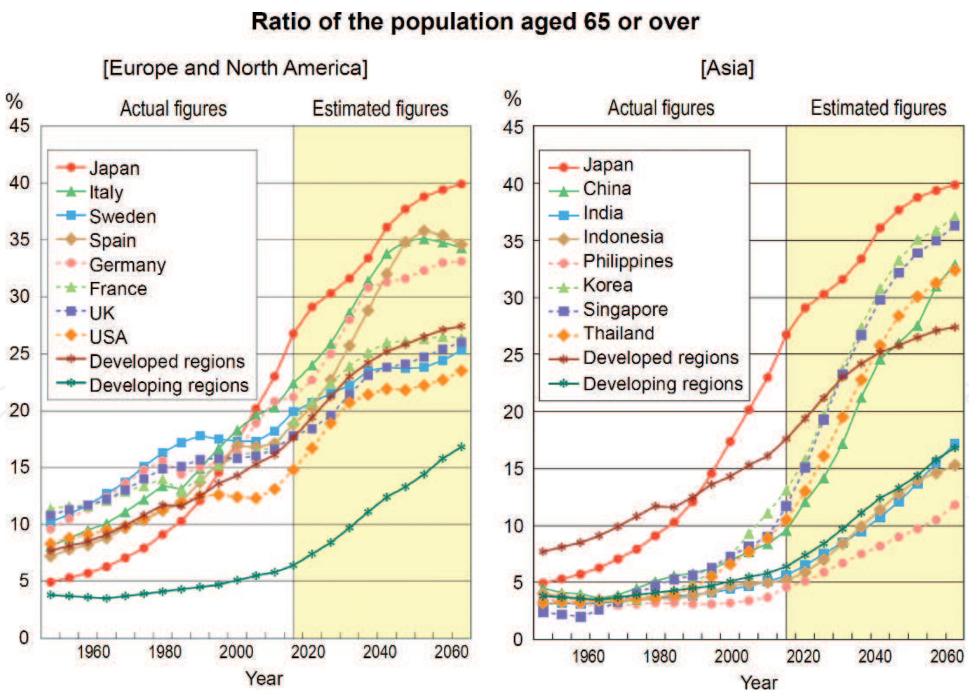

Figure 3. Ratio of the population aged 65 years or more [15]. Source: UN, World Population Prospects: The 2015 Revision. However, data on Japan are taken before 2010 from "Population Census" (Ministry of Internal Affairs Communications), 2015 from the estimated population based on the "2015 Population Census," and after 2020 from "Population Projections for Japan (January 2012 Estimates)" based on the estimated figure with Medium-Fertility and Medium-Mortality Assumption (National Institute of Population and Social Security Research).

such deaths demonstrate that as outdoor temperatures become lower, the more deaths occur [21, 23]. An important reason for frequent bath-related deaths in winter is poor thermal insulation performance of homes. In many cases, elderly people move from a locally heated living room to a cold changing room and bathe in hot water. As a result, exposed to sudden temperature changes, they have a stroke, myocardial fraction or faint, and finally, drown [21, 23].

Meanwhile, in summer, the recent increases in heat stroke patients and deaths (**Figure 1**) are also related to aging population as well as rise in temperature [4, 5]. The ratios of the elderly to the total heat stroke patients and deaths have been increasing. For example, the ratio of the elderly to the total heat stroke deaths rose from 54% in 1995, to 72% in 2008, and 79% in 2010 [4]. At the same time, the number of elderly people having heat stroke in their "homes" has also been growing. Heat stroke cases in "homes" account for over 50% of the total heat stroke cases of elderly in recent years [4]. Surveys in Japan have indicated that countermeasures against heat stroke include improvement in housing thermal performance, such as thermal insulation performance and sunlight adjustment capability [24].

3.3. Fall-and-slip–related injuries in homes

In addition to thermal performance–related illnesses and deaths, fall-and-slip–related injuries in homes are also a serious health problem. In Australia, slips, trips, and falls in buildings constitute a large and costly public health problem, which is expected to grow due to aging of the Australian population. The most common place of occurrence has been in the "home", which accounts for 62% of all fall-and-slip–based injuries, according to a survey conducted from 2002/02 to 2004/05. The total hospital cost for such home injuries in this period has been estimated at about 1.8 billion A$ [25].

Also in Japan, slips and falls in homes is a major problem which requires a large amount of medical costs. **Table 4** shows the extract of the data on accidents involving injuries of adults that Consumer Affairs Agency, Government of Japan and National Consumer Affairs Center of Japan, have collected from 13 medical institutions. The place where accidents occur most frequently is the "home." The ratios of accidents occurring in homes to all accidents have exceeded 70% in all of the three age groups. Next, breaking down the data by causes of accidents, we realize that the ratios of accidents caused by "falls" and "slips/trips" increase with age. Moreover, the ratios of "middle-level injury" and "serious/critical injury and death" are higher in elderly people, especially in the group of "75 years old or over" [26]. In addition, "middle-level injury" is the severity of injuries, which hospitalization is necessary, but the injury is not life-threatening. These figures show a tendency of an increase in the degree of severity in accordance with aging.

3.4. Need for accessibility and universal design in homes

In order to prevent accidents involving injuries, homes need to improve safety. At the same time, aging population requires homes to have accessibility to disabled people. For instance, a research paper titled *Aging and Disability: Implications for the Housing Industry and Housing Policy in the United States* clearly raises a problem. "Since disability rates increase with age,

Age group		20–64	65–74	75+
Ratio of accidents involving injuries occurring in homes to all accidents		71.4%	72.4%	79.8%
Ratios of accidents caused by falls and slips/trips to all causes of accidents involving injuries in homes	Falls	17.8%	30.1%	30.6%
	Trips/slips	7.1%	18.2%	29.1%
	(Subtotal)	(24.9%)	(48.3%)	(59.7%)
Degree of severity	Slight injury	78.3%	64.2%	55.9%
	Middle-level injury	20.1%	31.3%	35.6%
	Serious/critical injury & death	1.6%	4.5%	8.5%

Note: "Slight injury" is the severity of injuries that does not require hospitalization. "Middle-level injury" is the severity of injuries that hospitalization is necessary but the injury is not life-threatening.

Source: National Consumer Affairs Center of Japan, 2013.

Table 4. Accidents involving injuries occurring in homes by age.

population aging will bring substantial increases in the number of disabled persons and have a significant impact on the nation's housing needs" [27]. In fact, disability rates rise in accordance with age, as shown in **Table 5**. "DIS-1" on the left side of this table means "individuals with physical limitations," which is defined as persons with long-lasting conditions that substantially limit one or more physical activities such as walking, climbing stairs, lifting, and carrying. On the other hand, "DIS-2" stands for "individuals with self-care limitations", which is defined as persons with conditions lasting 6 months or more that make it difficult to dress, bathe, or get around inside the home [27].

Furthermore, aging population will inevitably increase the number of households with at least one disabled resident over the next several decades. This study also estimates that there is a 60% probability that a newly built single-family detached unit will house at least

[DIS-1] Individuals with physical limitations			[DIS-2] Individuals with self-care limitations		
Age	Male (%)	Female (%)	Age	Male (%)	Female (%)
<35	1.8	1.7	<35	1.0	0.8
35–44	5.5	5.6	35–44	1.6	1.7
45–54	8.9	9.5	45–54	2.4	2.7
55–64	15.7	16.2	55–64	3.7	4.2
65–74	21.8	23.2	65–74	5.6	6.7
75–84	31.3	36.4	75–84	11.3	15.2
85+	47.3	60.8	85+	24.7	37.7

Note: Data are for the population aged 5 and older.

Table 5. Individual disability rates by age and sex in the US in 2000 [27].

one "DIS-1" disabled resident during its expected lifetime and a 25% probability of housing at least one "DIS-2" disabled resident. The authors of the study recommend that planners should broaden their vision of the built environment to include the accessibility of the housing stock [27].

Incorporating "universal design" features into homes and improving accessibility brings various benefits. Universal design is defined as the design of products, environments, programs, and services to be usable by all people to the greatest extent possible, without the need for adaptation or specialized design [28]. The concept of universal design emerged primarily with people with disability in mind. However, universal design helps everyone with support and assistance needs including the elderly, pregnant women, children, and people with a temporary illness or injury. Thus, the benefits of implementing universal design are wide [29].

In addition to "improving home safety" and "savings for government", the inclusion of universal design features in a new home brings "reducing renovation costs". A universally designed home should (1) be easy to enter; (2) be easy to move around in; (3) be capable of easy and cost-effective adaptation; and (4) be designed to anticipate and respond to the changing needs of home occupants [30]. Research suggests that incorporating universal housing design principles in advance has a minimal impact on the cost of construction. The Victorian Government of Australia has estimated the cost of including fundamental universal housing design features in a new home is 22 times cheaper than retrofitting those features into an existing home [31].

4. Toward a new comprehensive sustainable design

Homes need to be designed and constructed, so as to meet comprehensive sustainability objectives. Providing a refuge from the climate and weather, homes are expected to protect the occupants' health, safety, and well-being, as well as to reduce the burden on the natural environment.

In the twenty-first century, houses are also necessary to suit two major significant changes, namely "climate change" and "aging population". In order to curb the progress of climate change, the housing industry must intensify "mitigation" measures, such as improvement in energy efficiency and the utilization of renewable energy. It also has to strengthen "adaptation" measures against adverse effects caused by climate change, aiming to prevent or reduce damage from extreme weather events, such as intensified heat waves, rainfall, and cyclones. On the other hand, housing needs to be transformed into those which help to reduce medical and nursing care expenditure in aging population. For example, homes with higher thermal performance contribute to reducing elderly people's diseases, such as circulatory disorders in winter and heatstroke in summer. Meanwhile, incorporating accessible and universal design into houses brings various benefits, including the prevention of injuries, increase in occupants' mobility, and reduction in future renovation costs.

Houses are used for a very long time. Accordingly, in addition to usual sustainability objectives, the above emerging requirements should also be met in housing design from the beginning. Furthermore, in order to satisfy these requirements inclusively, efficient methods for new comprehensive sustainable housing design need to be developed and moreover disseminated in the society.

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